A Novel Strategy for Monitoring Laser Thermal Therapy Based on Changes in Optothermal Properties of Heated Tissues

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Interstitial laser thermal therapy is a minimally invasive technique whereby optical energy is deposited into a solid tumor through implanted optical fibers, to heat the tissue to above 55 C, which results in thermal coagulative necrosis. Induced thermal damage can be variable and unpredictable due to thermally-induced changes in tissue thermal and optical properties and blood perfusion. A typical thermal lesion has a central charred zone surrounded by zones of tissue browning, dehydration, coagulation (observed as tissue whitening) and edema, each with varying thermal and optical properties. Tissue browning increases optical absorption and char (observed at temperatures ~400 C) is opaque, converting the optical source into effectively a point heat source for the remainder of the exposure. Tissue charring is to be avoided as it is concomitant with smoke production and the extreme temperatures can damage the optical fiber. However, it will be shown that this is made difficult due to the somewhat aleatoric nature of browning/ charring onset. It is therefore important to include on-line monitoring to compensate for these factors. The effectiveness of point temperature measurements to control heating is limited, due to the induced steep temperature gradients and the time delay in the arrival of thermal energy to a temperature sensor. In this work, we show that monitoring the onset and propagation of tissue coagulation, by measuring changes in optical intensity is an improved approach as 1) the occurrence of thermal damage can be detected immediately due to the speed of light in tissues and 2) optical readings are indicative of a larger “sampling volume” than temperature readings. Measured optical intensities at 10 mm from a heating fiber in ex-vivo bovine liver and in-vivo porcine kidney show a continuous loss in optical intensity as the coagulation boundary expands, and a rapid drop in intensity at the onset of tissue charring. The utility of optical monitoring to record important treatment events such as tissue coagulation, browning and charring will be discussed.